update on HERA-B results

Pietro Faccioli (Bologna University and INFN) *for the HERA-B Collaboration*

QWG Workshop – October 18th, 2007

- ***kinematics of J/ψ production***
  - nuclear effects in longitudinal and transverse momentum distributions
  - polarization

under finalization but still preliminary

- ***fraction of J/ψ's from χ_c***

NEW, close to final

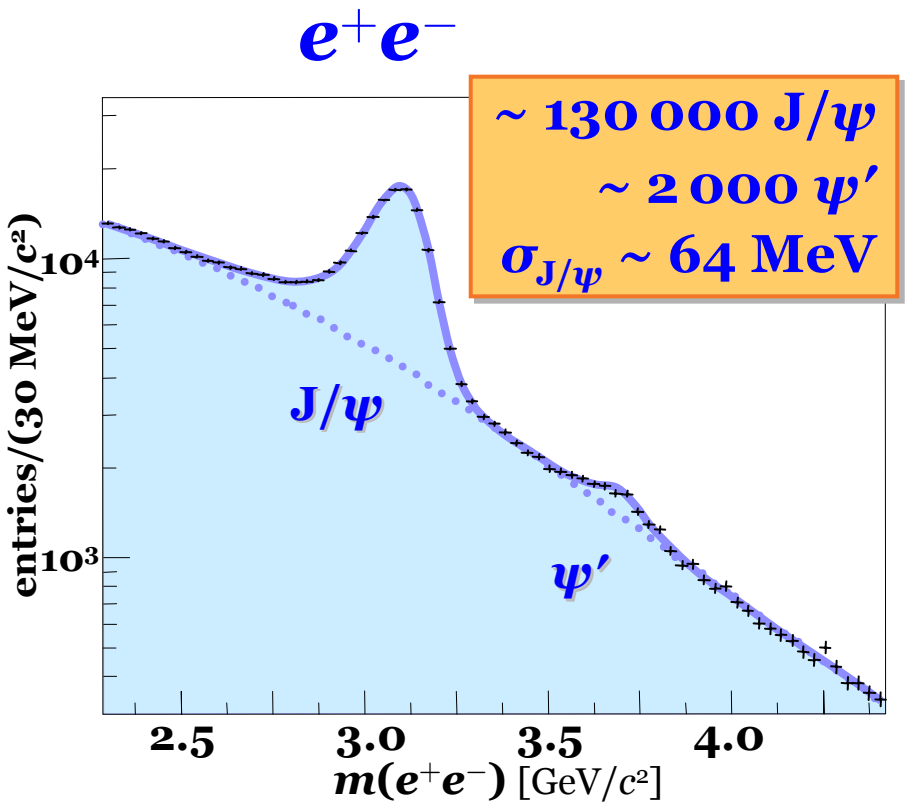
already published:
- ψ'
- J/ψ's from b
- Υ

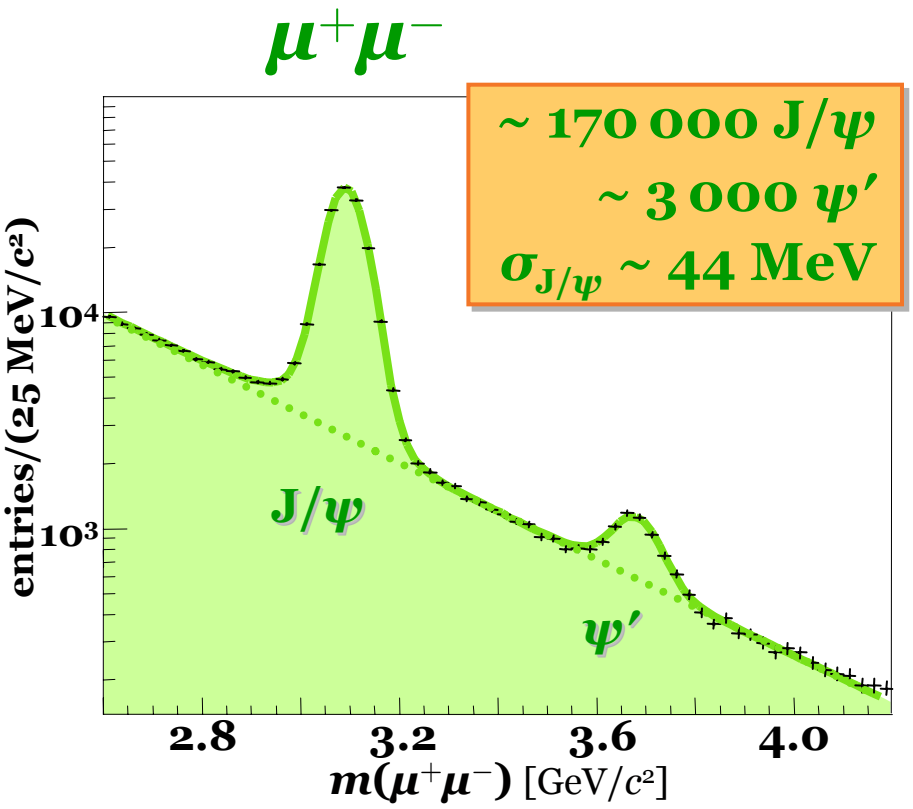
charmonium at HERA-B

- **fixed-target proton-nucleus (C, Ti, W) at $\sqrt{s}$ = 41.6 GeV**
- **negative x_F (-0.35 < x_F < 0.15)**
- **two partially independent analyses (J/$\psi \rightarrow e^+e^-$ *or* $\mu^+\mu^-$)**

J/ψ and ψ′ signals

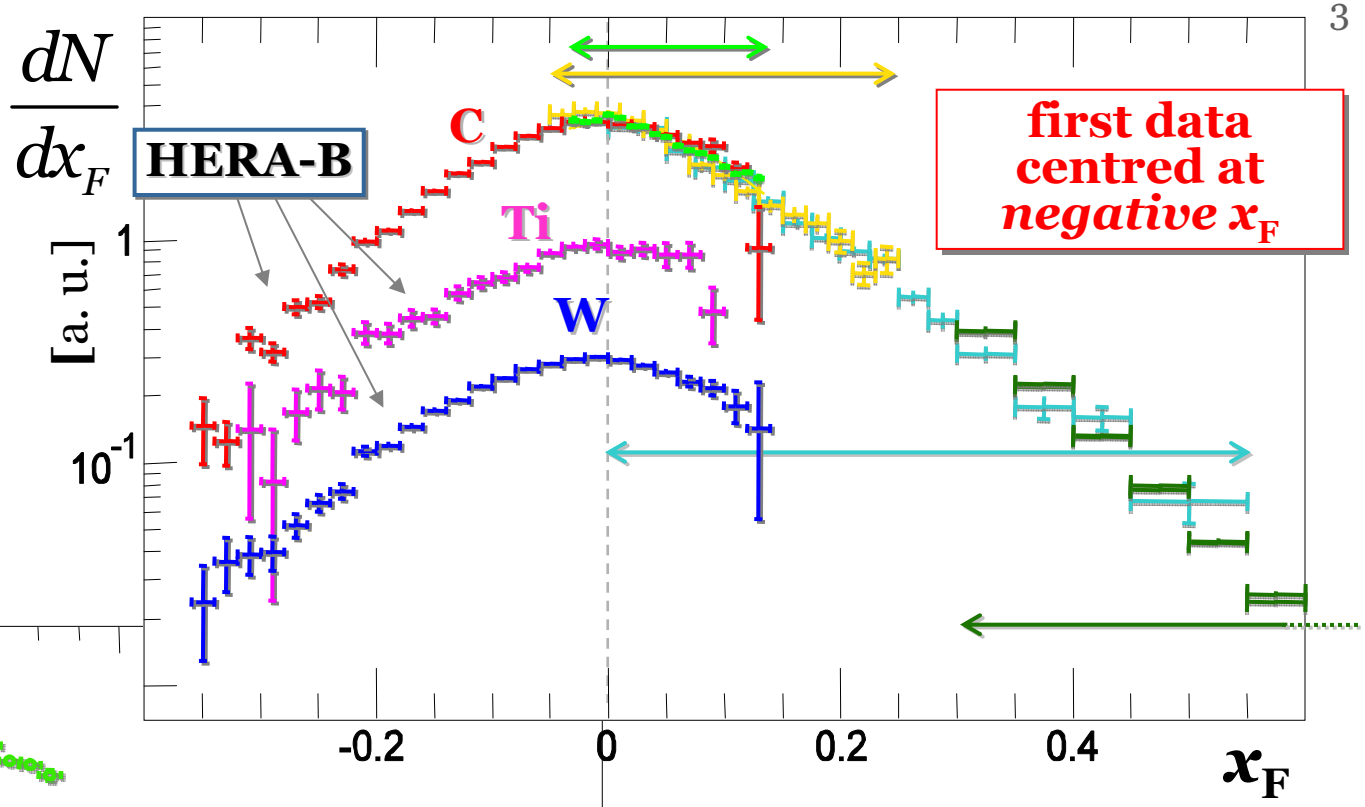
full dilepton data sample (3 target materials)

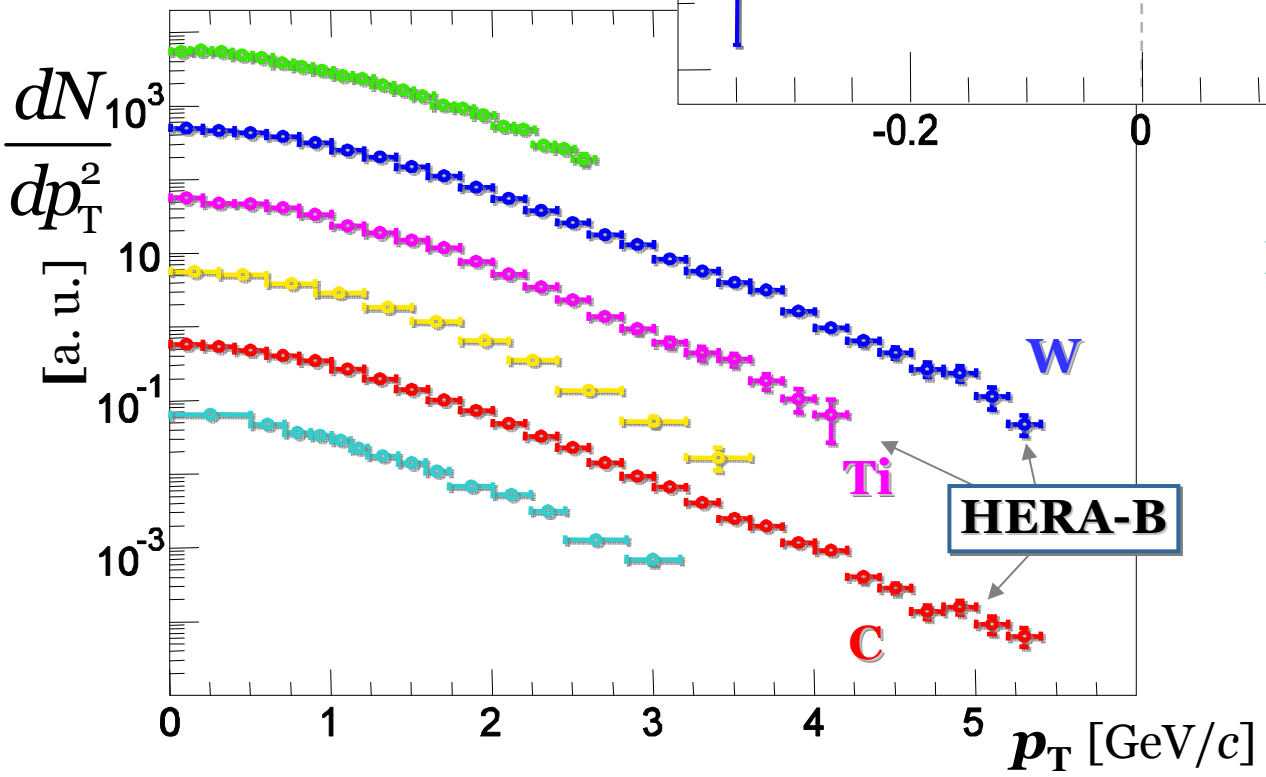




J/ψ production kinematics – UNDER FINALIZATION

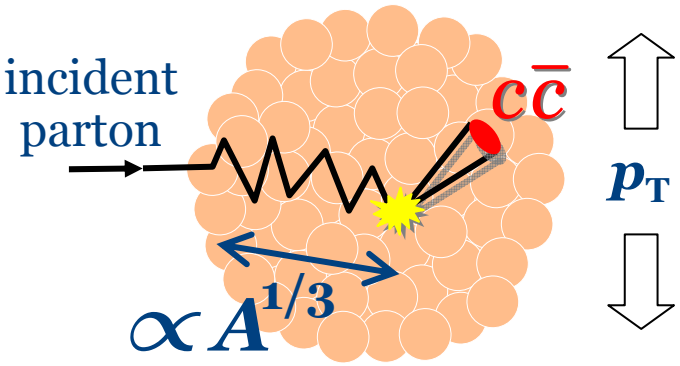
comparison with *p-A* results at 38.8 GeV

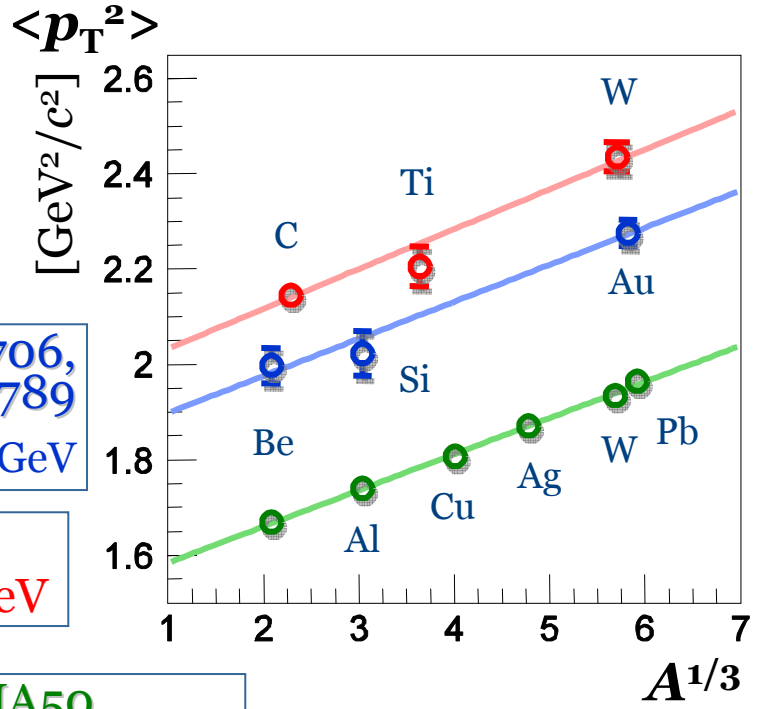




E672/E706 (Be)
E771 (Si)
E789 (Au)
E789 (Be, Cu)

nuclear effects: p_T ditribution



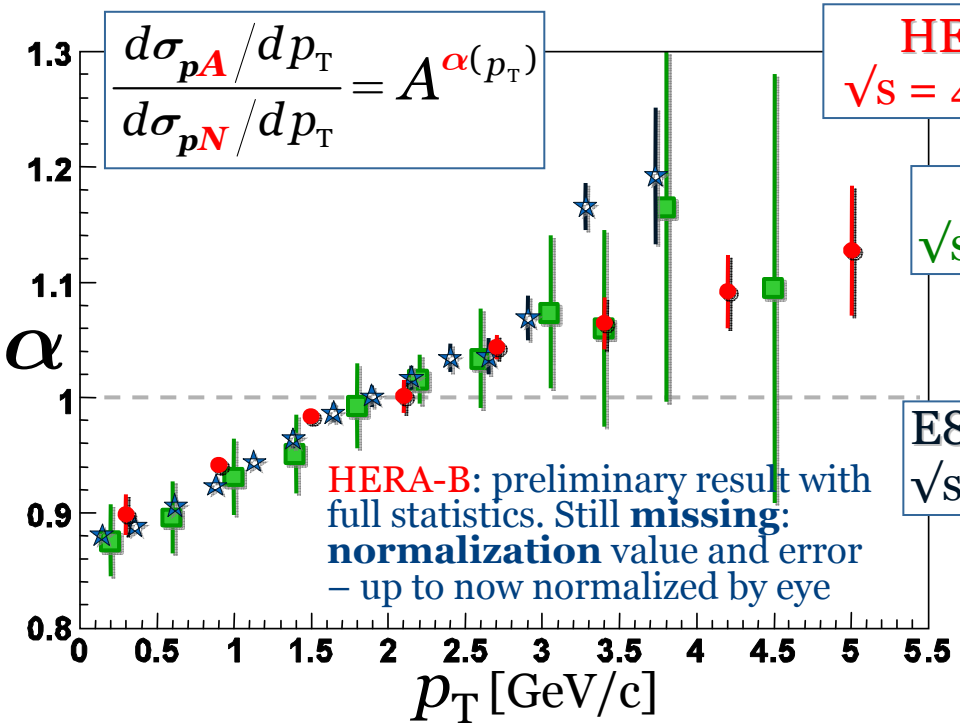


E672/706, E771, E789
$\sqrt{s}$ = 38.8 GeV

HERA-B
$\sqrt{s}$ = 41.6 GeV

NA50
$\sqrt{s}$ = 27.4/29.1 GeV

E866
$\sqrt{s}$ = 38.8 GeV



$\alpha(p_T)$ has very similar behaviour at different energies and in different x_F ranges

$-0.35 < x_F < 0.15$

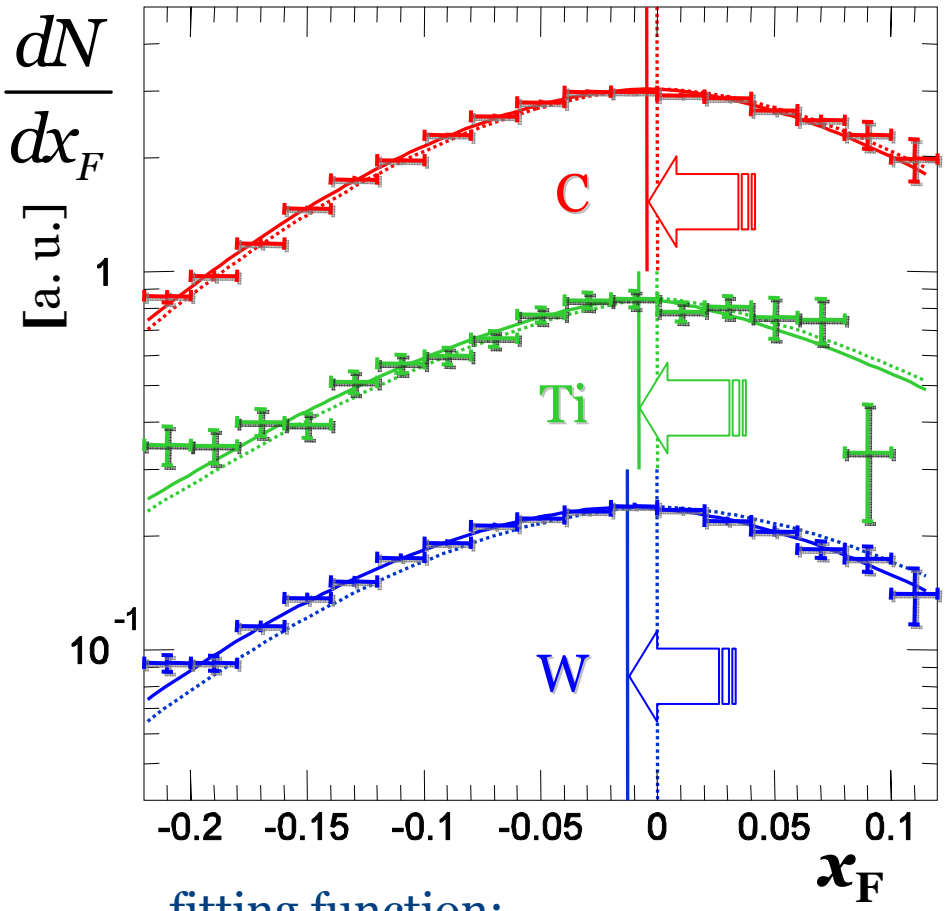
$-0.1 < x_F < 0.9$

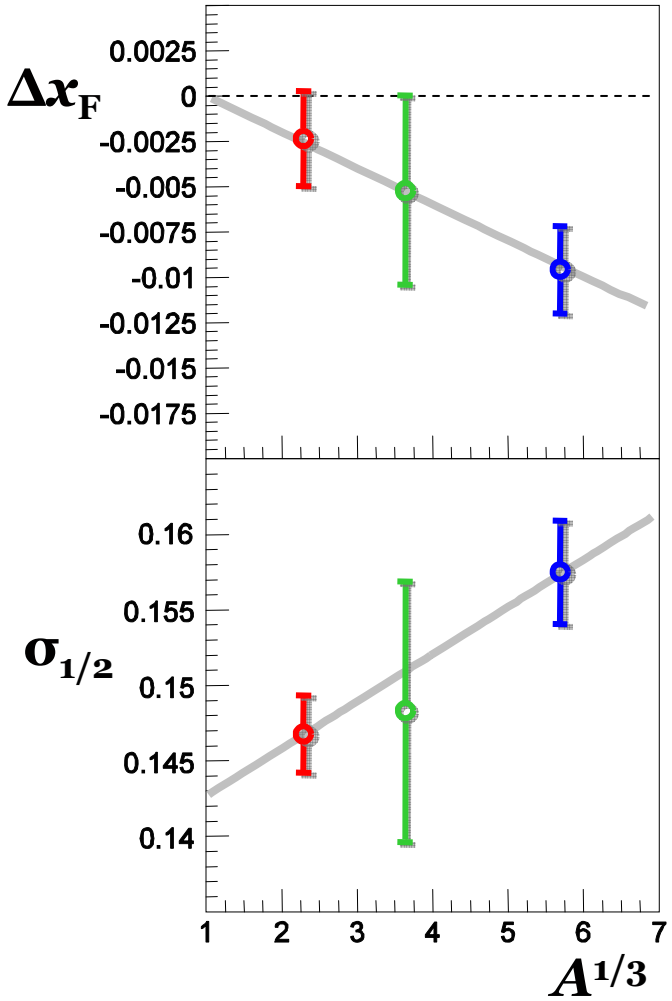
$-0.1 < x_F < 0.1$

nuclear effects: x_F ditribution

- shift towards negative x_F
- increasing width

both effects consistent with $A^{1/3}$ behaviour: energy loss?





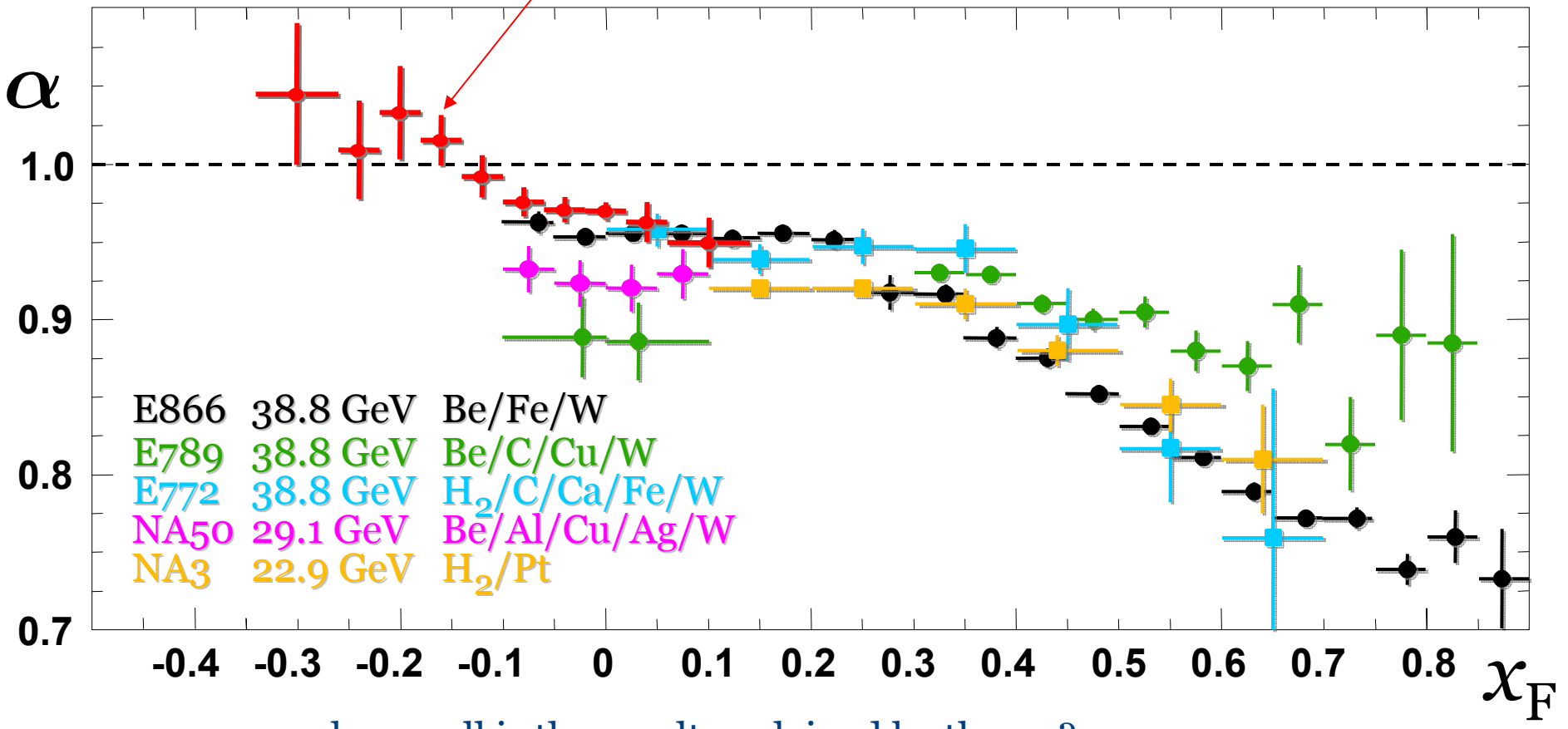
fitting function:

$$f(x_F) \propto \exp[-\ln 2\,(|x_F - \Delta x_F| / \sigma_{1/2})^{\alpha}]$$

$\alpha(x_F)$

$$\frac{d\sigma_{pA}/dx_F}{d\sigma_{pN}/dx_F} = A^{\alpha(x_F)}$$

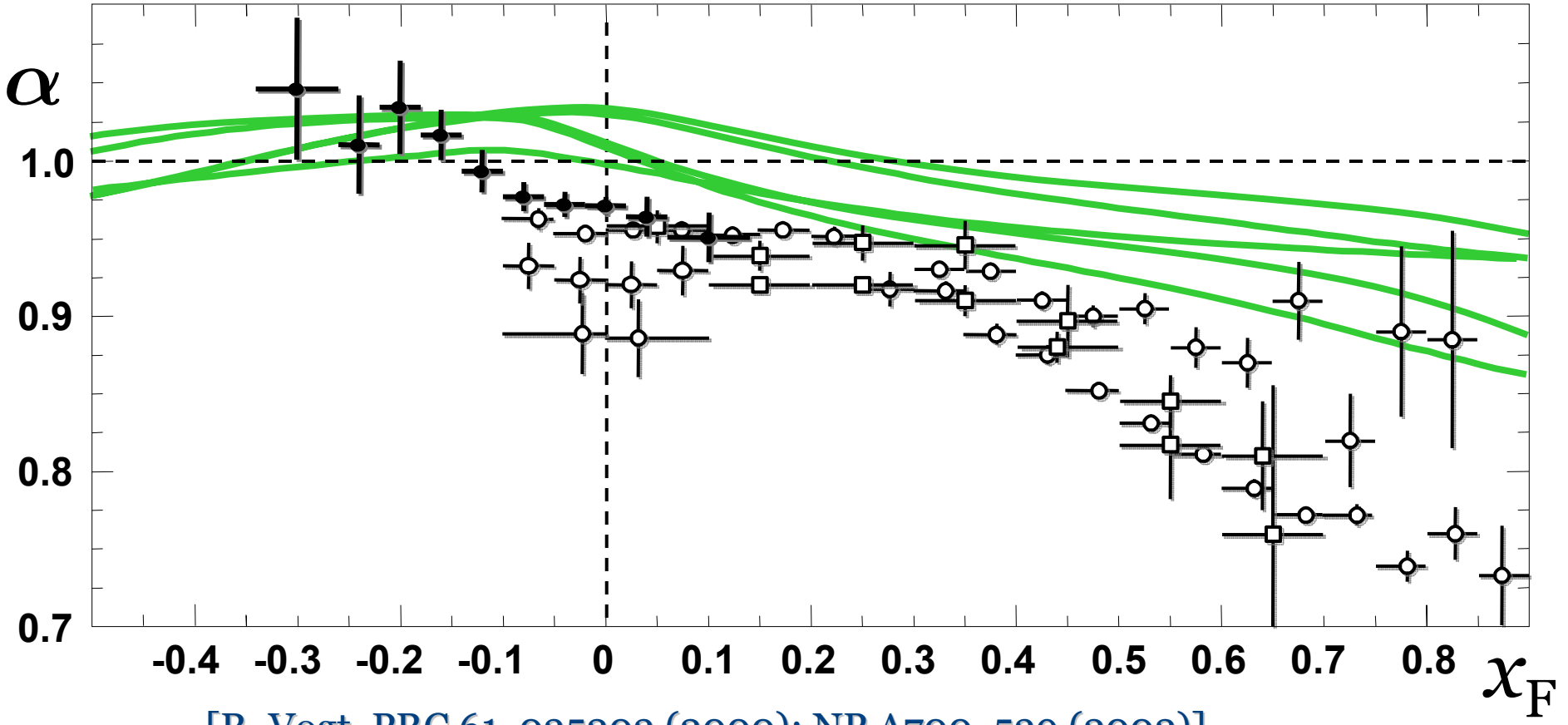
HERA-B: preliminary result with full statistics.
still missing: normalization value and error –
up to now normalized by eye to E866



how well is the result explained by theory?

theory

- modification of the PDFs of nucleons bound in the nucleus
- initial/final state energy loss
- interaction with comovers produced together with $c\bar{c}$
- intrinsic charm components of beam/target nucleons
- absorption of $c\bar{c}$ inside the nucleus



[R. Vogt, PRC 61, 035203 (2000); NP A700, 539 (2002)]

theory

- modification of the PDFs of nucleons bound in the nucleus
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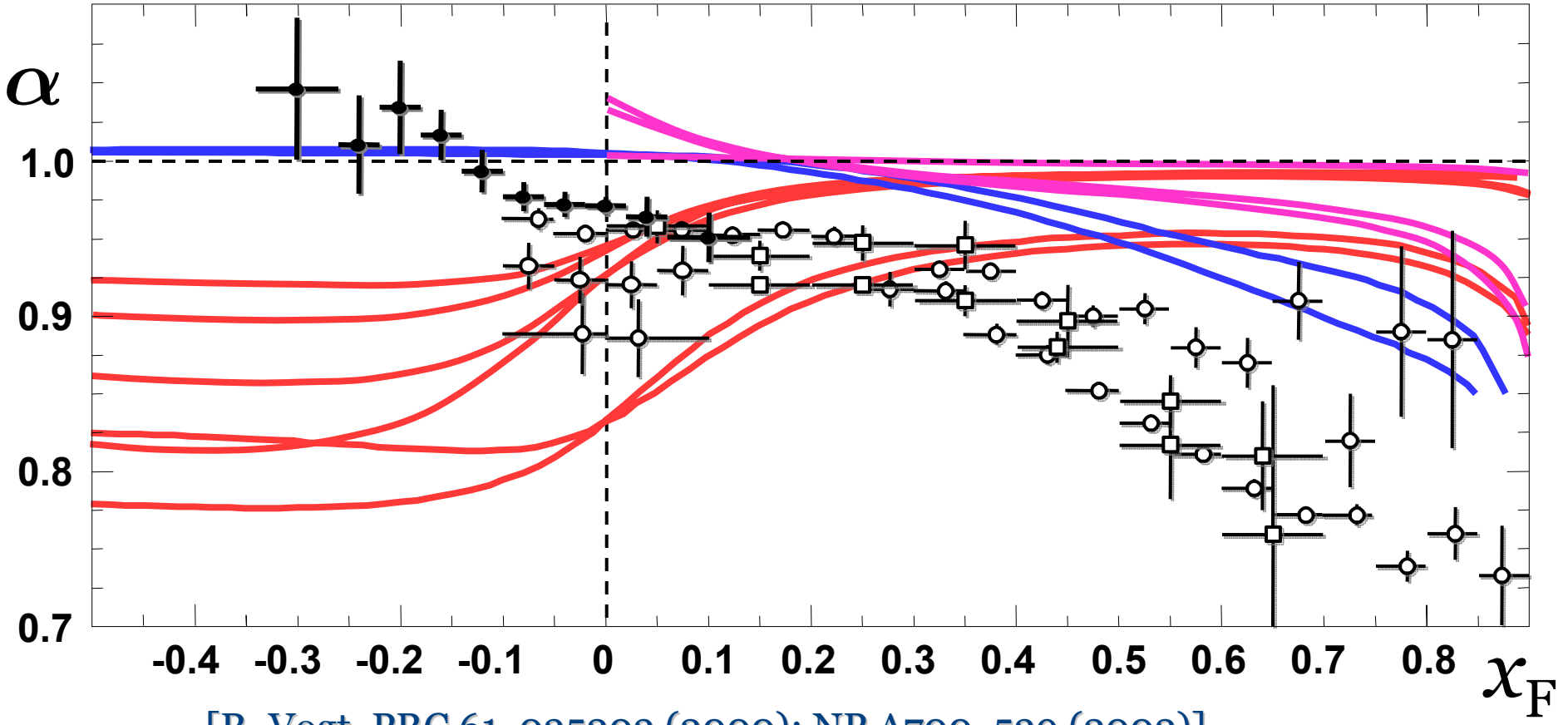

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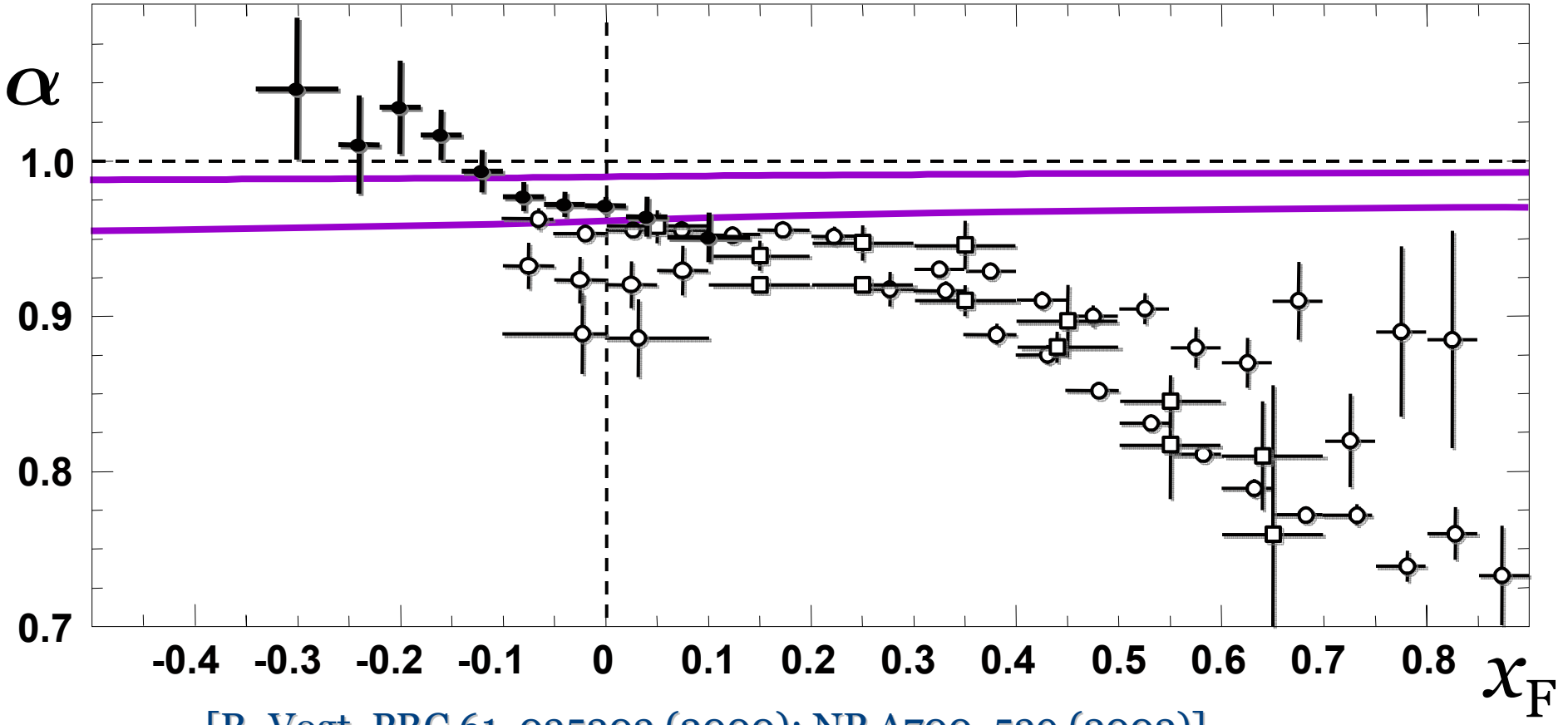

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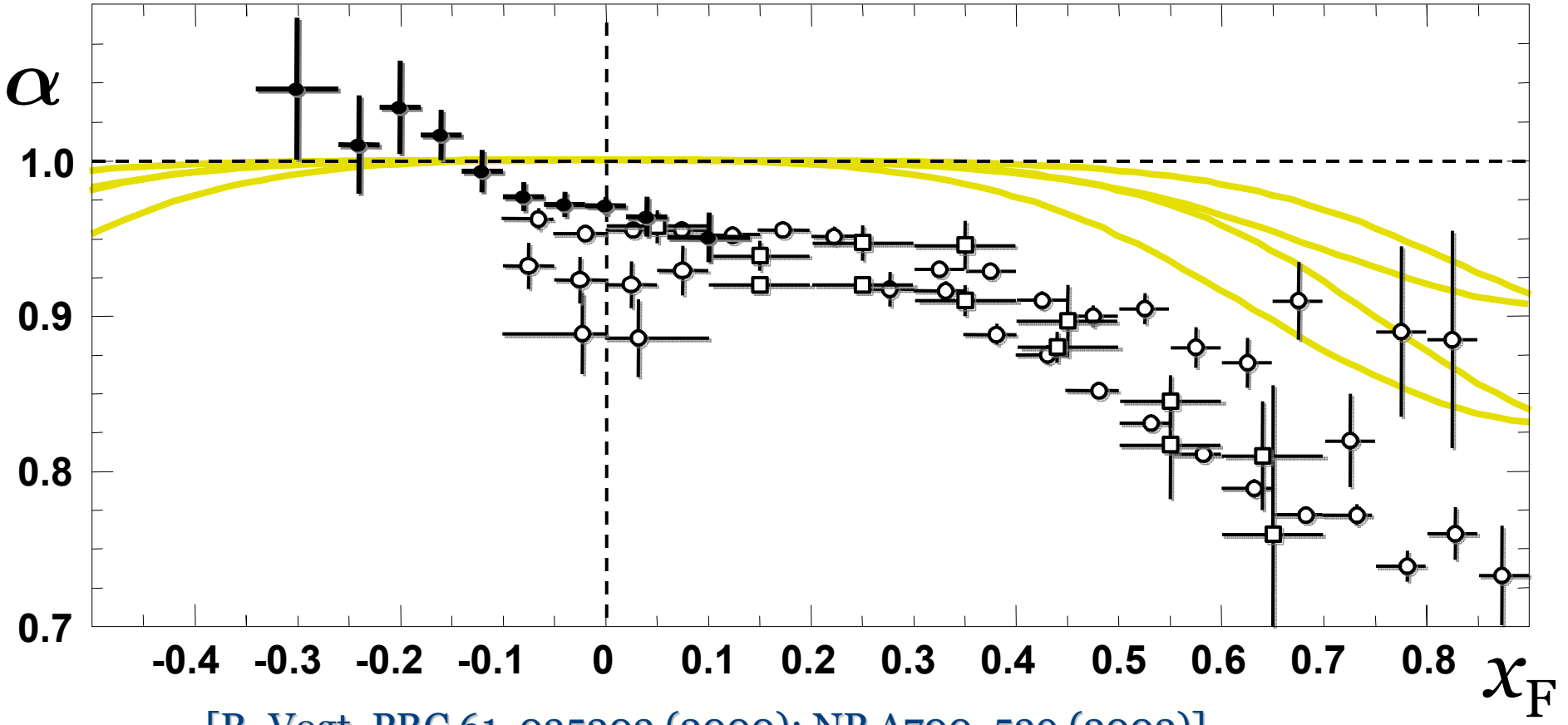

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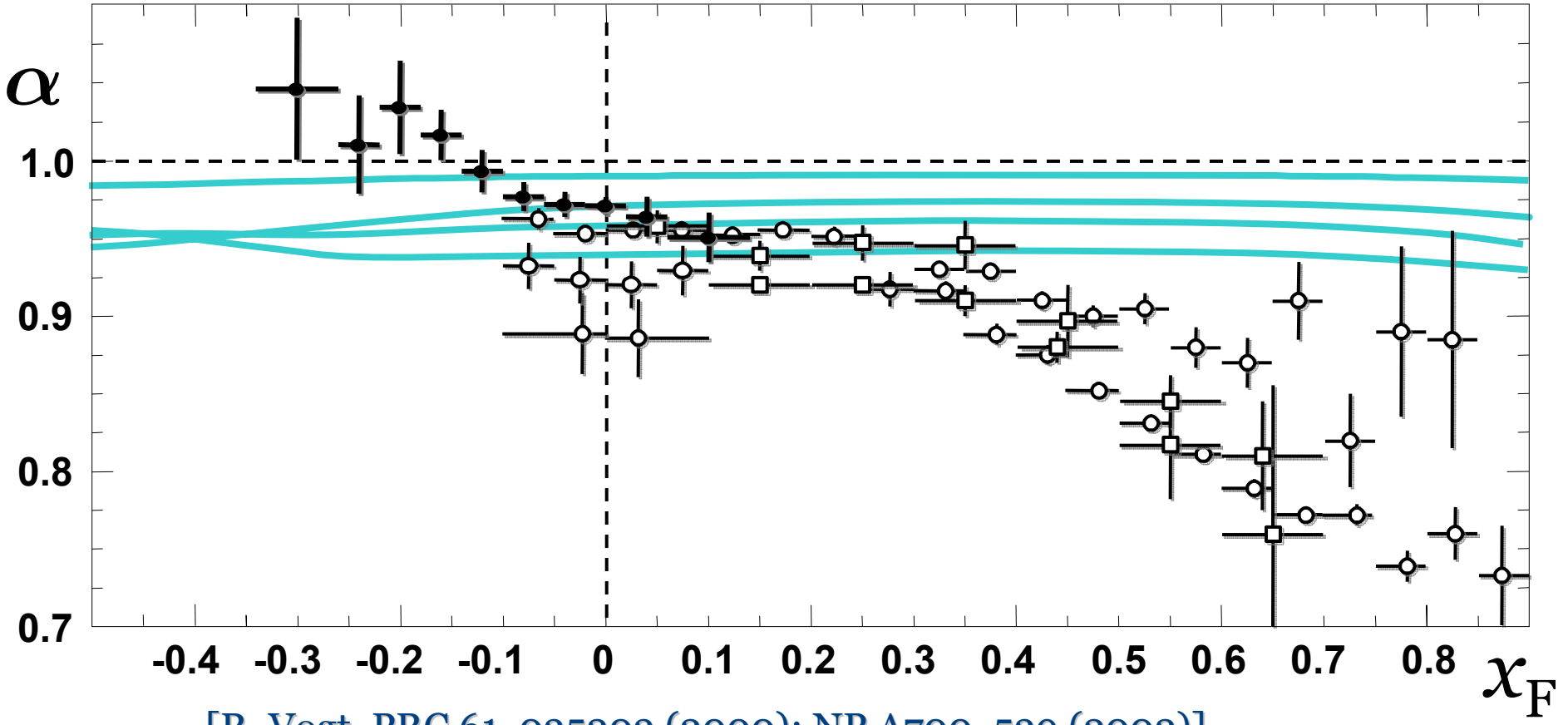

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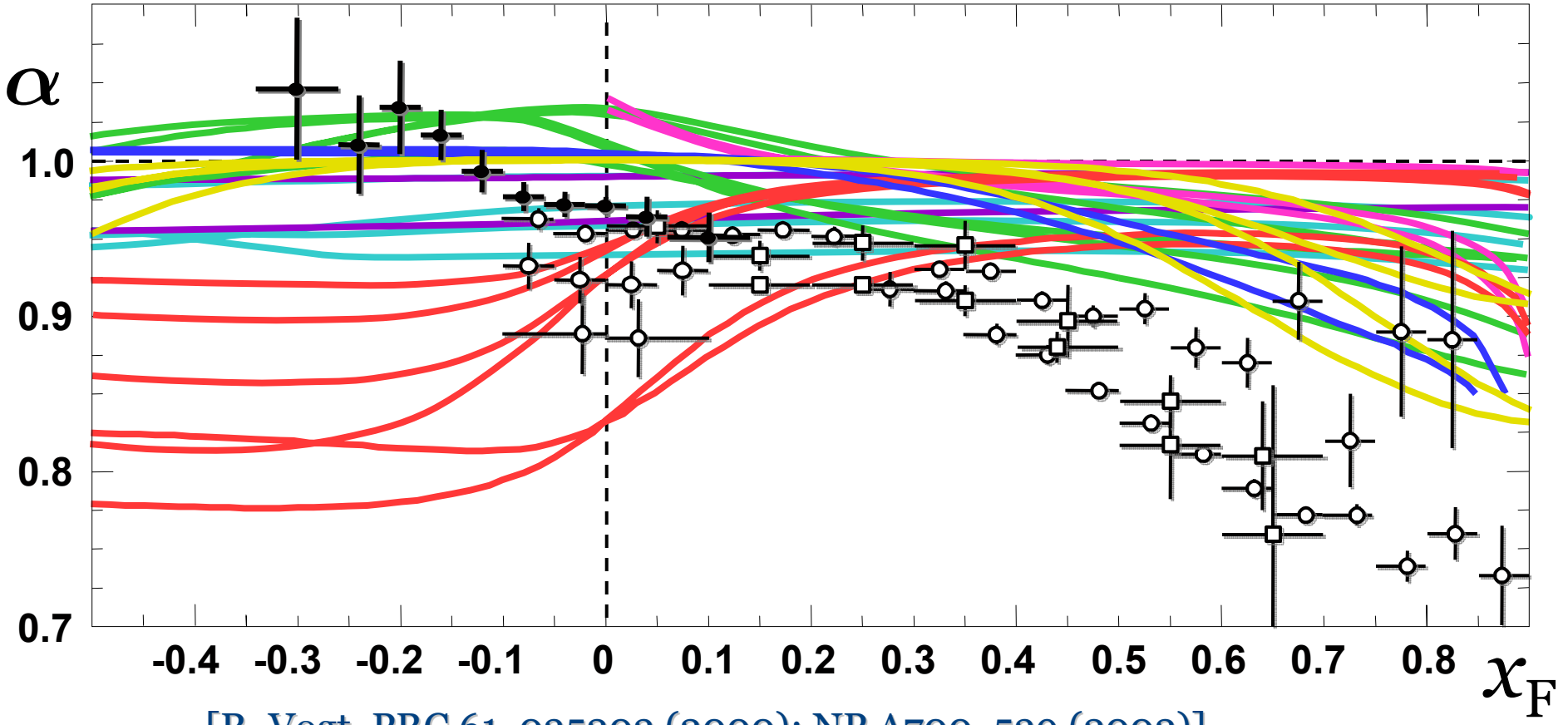
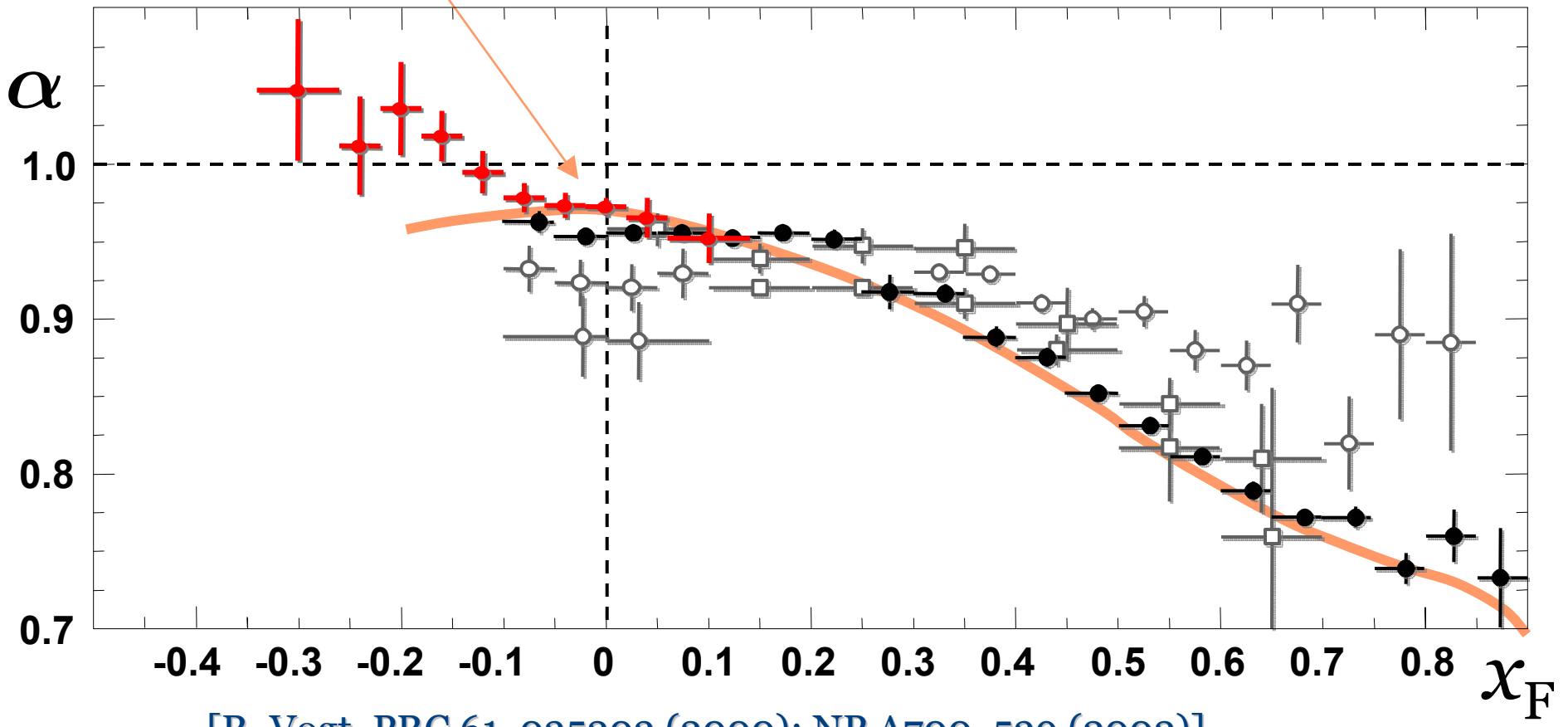


[R. Vogt, PRC 61, 035203 (2000); NP A700, 539 (2002)]

theory

one possible combination of all effects (Vogt)
(*model parameters adjusted to E866 data*)

missing ingredient in the calculations of final-state effects: precise knowledge of the feddown components of J/ψ production. Assumed (Vogt): 12% from ψ', 30% from χ_c

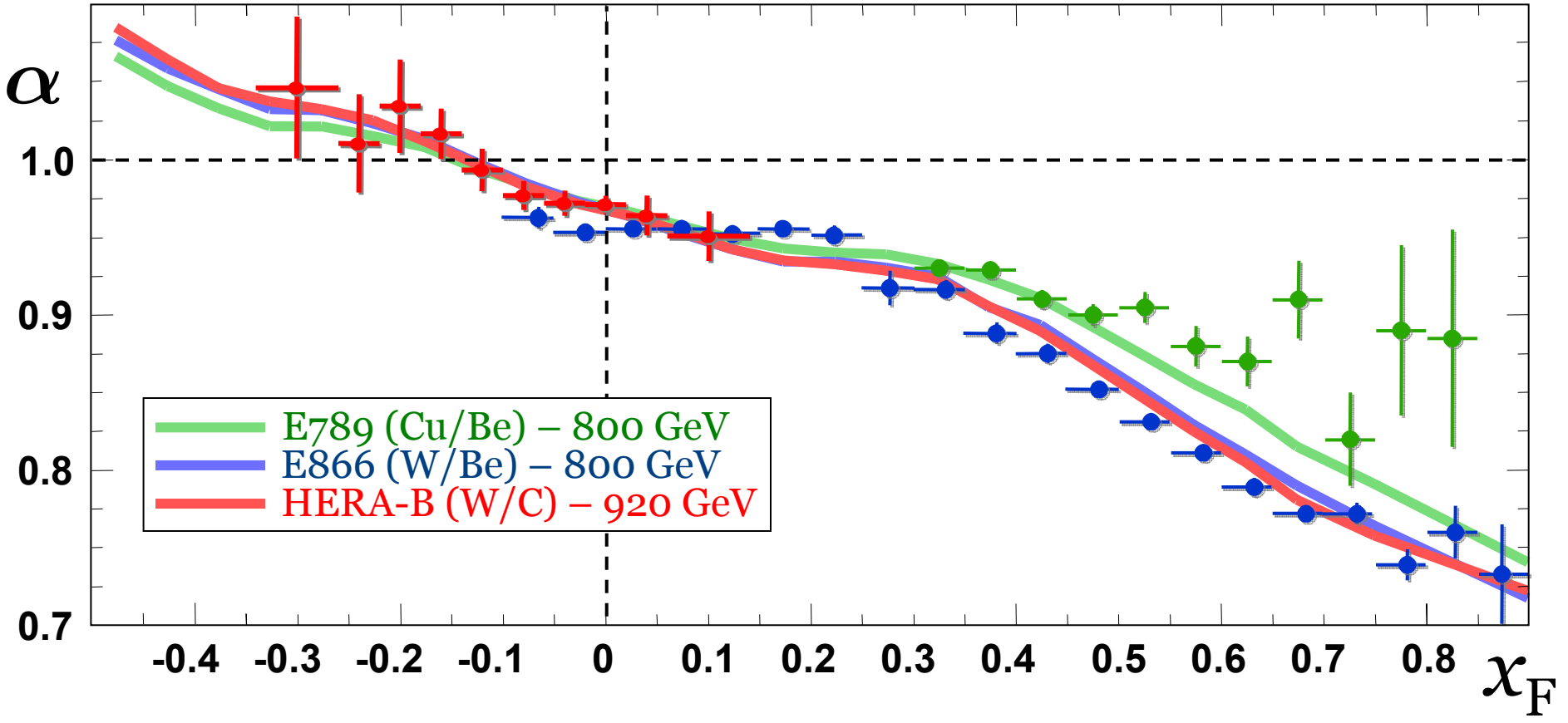


[R. Vogt, PRC 61, 035203 (2000); NP A700, 539 (2002)]

energy loss ?

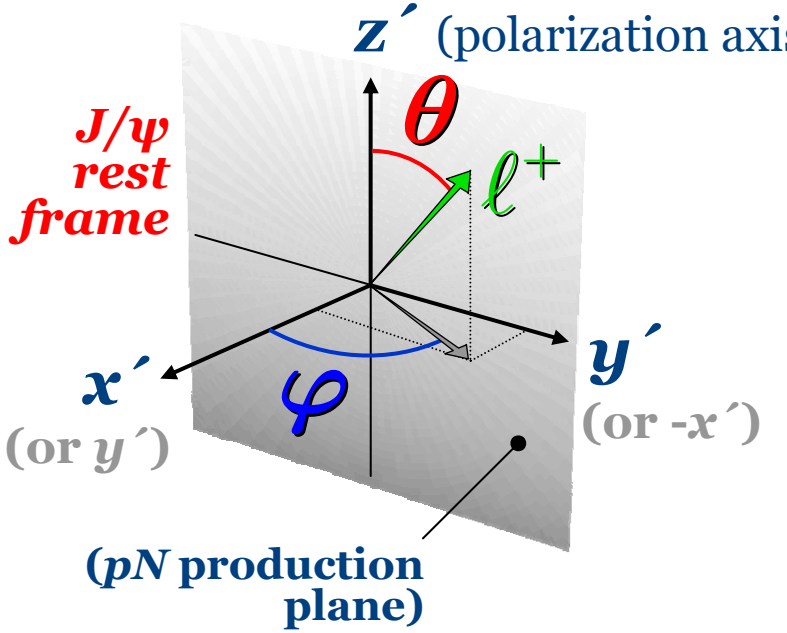
example: rough assumption $\langle \Delta p^{LAB}/p^{LAB} \rangle = -1.5\% \cdot A^{1/3}$
+ residual, constant "absorption" $\Delta\alpha = -0.025$

increase at *negative* x_F due to p_T broadening – hypothesis: beam parton does not *increase* its energy with multiple scattering (bigger $k_{T1} \rightarrow$ smaller k_{L1}^{lab})



the $\sim A^{1/3}$ dependence of the effect seems to reproduce part of the difference between E789 and E866

J/ψ decay angular distribution: frames, angles, parameters



2 degrees of freedom: **cosθ, φ**

3 parameters: λ_θ, $\lambda_{\theta\varphi}$, $\lambda_{\theta\varphi}$

$$\frac{dN}{d(\cos\theta)d\varphi} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_{\theta\varphi} \sin 2\theta \sin\varphi \,(\cos\varphi) + \lambda_\varphi \sin^2\theta \cos 2\varphi$$

2-body parity-conserving decay

λ_θ = **"polarization"**

< 0: longitudinal

> 0: transverse

definitions of the polarization axis used by experiments:

1) Collins-Soper (**CS**): bisector between **beam and (–)target directions** in the J/ψ rest frame → **E866, NA3, etc.**

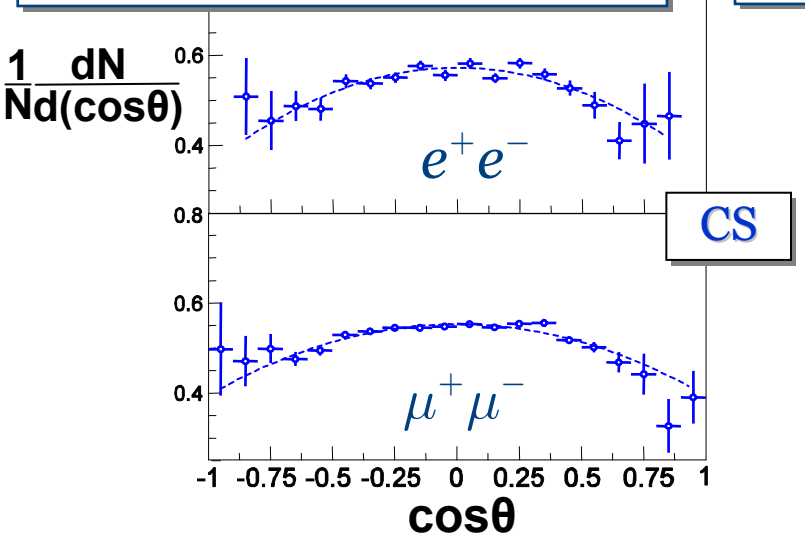
2) Gottfried-Jackson (**GJ**): **beam direction** in the J/ψ rest frame → **E615, E672-706, E771, E537, etc.**

3) helicity (**HE**): **J/ψ direction** in the **hadron** (p-N) **CM frame** → **CDF, NA60, etc.**

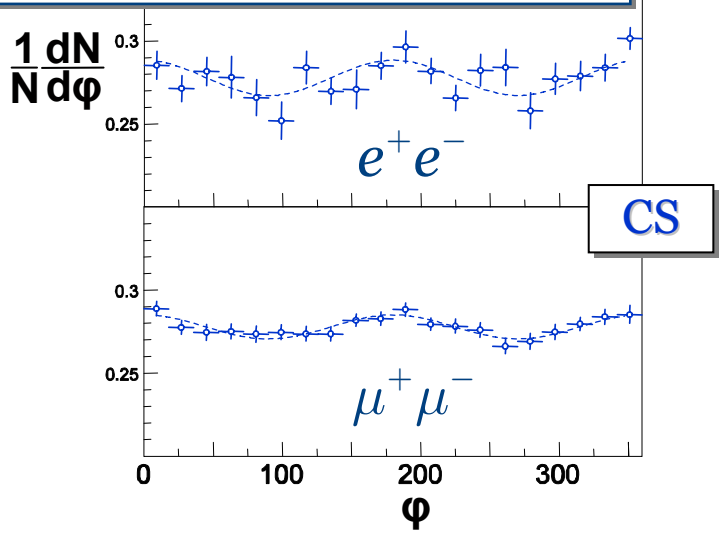
J/ψ polarization – UNDER FINALIZATION

1) we observe significant signals of anisotropy of the decay angular distribution in both channels and in all data samples: the J/ψ is ***longitudinally*** **polarized**

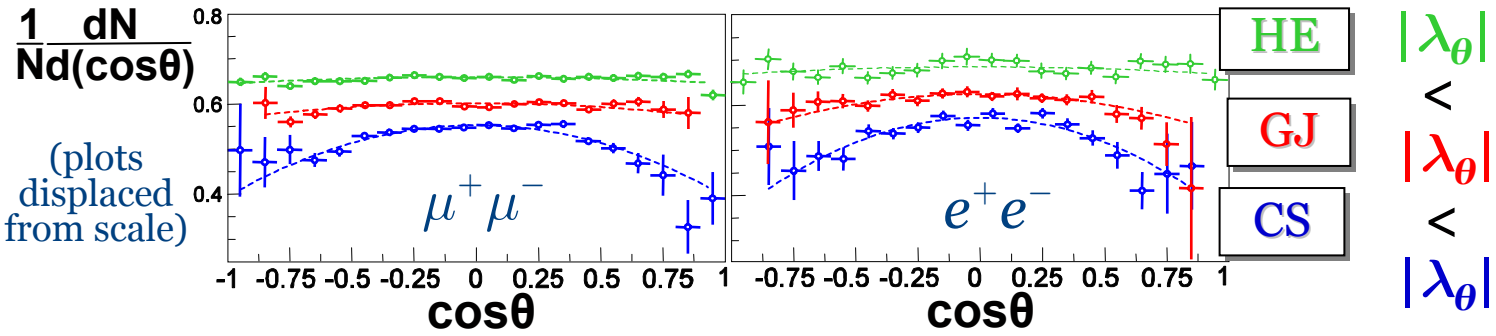
$dN/d(\cos\theta) \propto 1 + \boldsymbol{\lambda_\theta} \cos^2\theta$



$dN/d\varphi \propto 1 + 2\boldsymbol{\lambda_\varphi}/(3 + \lambda_\theta) \cos(2\varphi)$

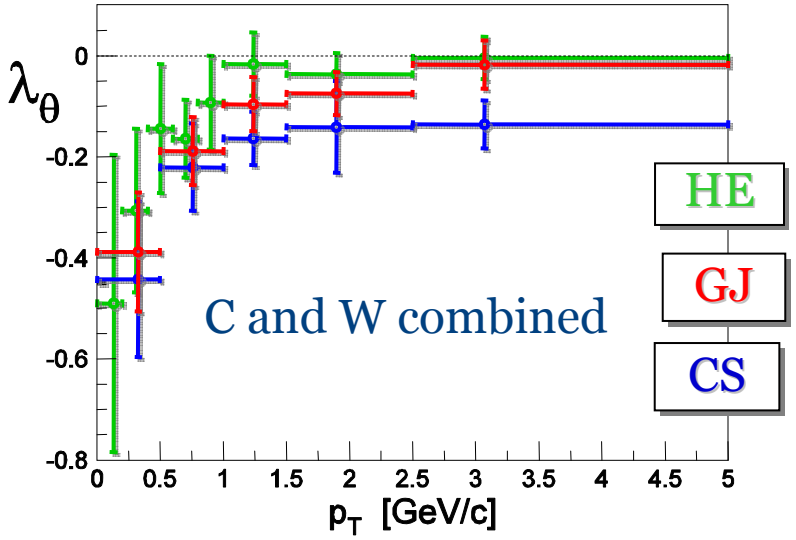


2) the results depend strongly on the **choice of the polarization frame**: the polarization is large in the CS frame, much attenuted in the helicity frame



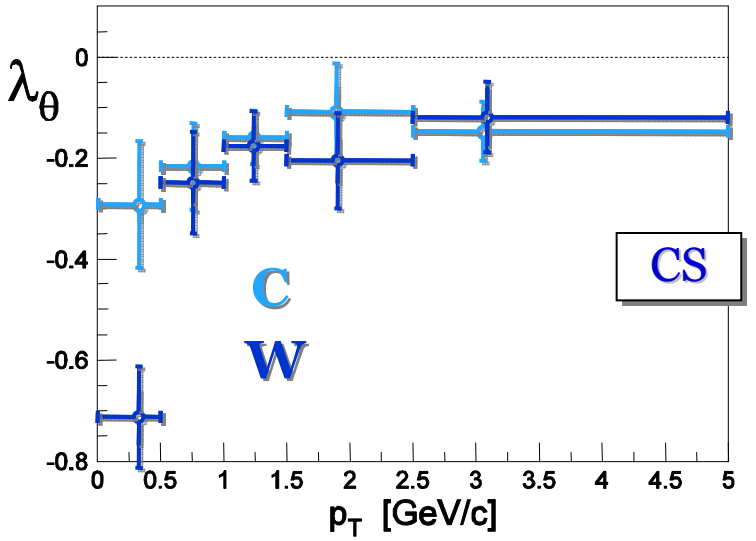
J/ψ polarization

3) we observe a peculiar kinematical behaviour: the polarization **increases with *decreasing* p_T**. At $p_T = 0$ the results in the three frames converge, as they should, to the same value



4) there is a possible **dependence on the target material (?)**

- role of feeddown from χ_c (with non-flat nuclear dependence of $R_{\chi c}$)?
- other nuclear effects?
- statistical fluctuation + still unaccounted-for systematics?

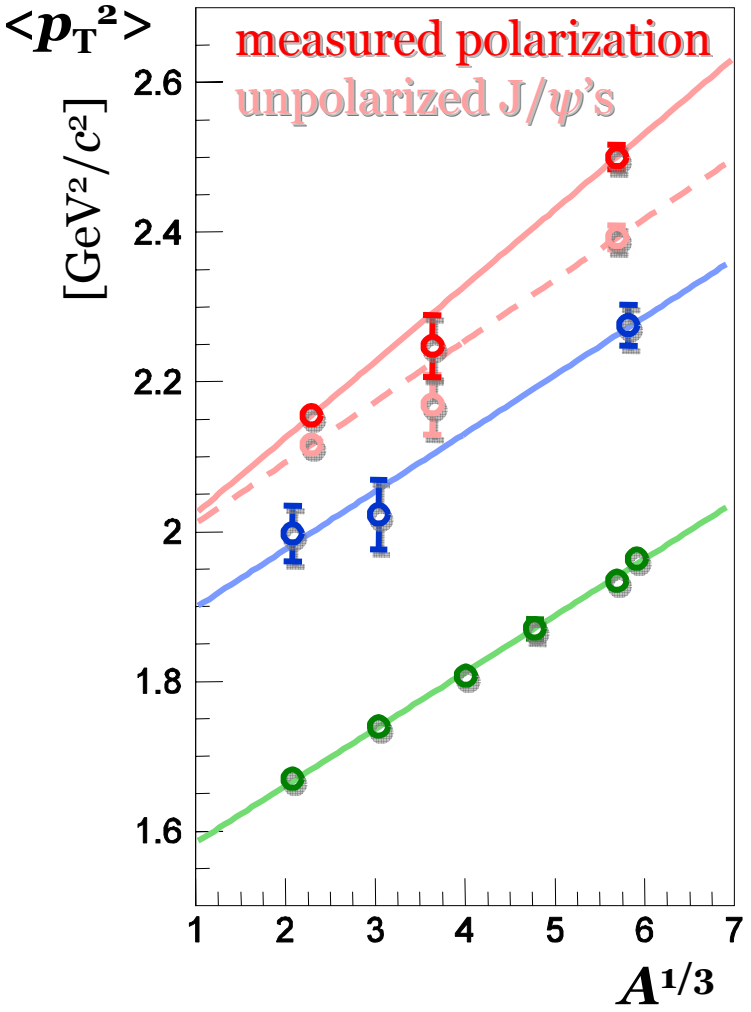


J/ψ polarization

5) technical issue: polarized J/ψ's are reconstructed with higher **efficiency** → influence on p_T distributions and on all analyses which give results on – or normalize to – the J/ψ yield.

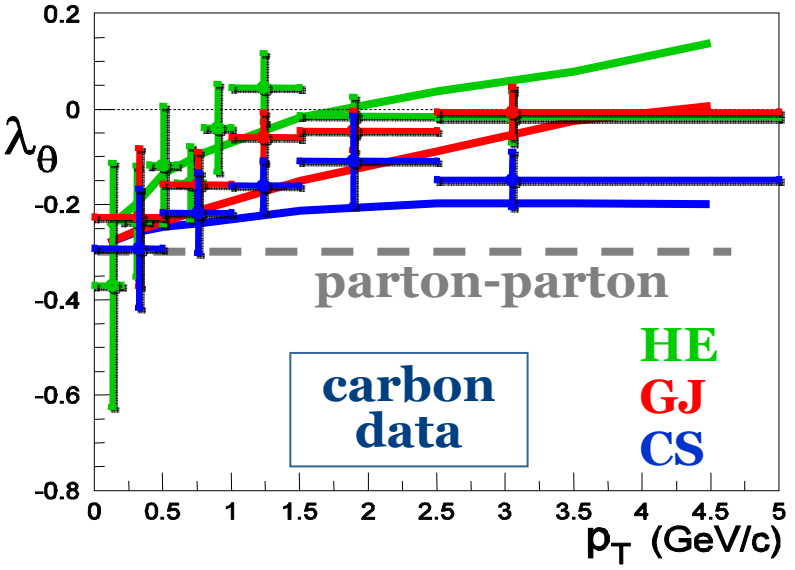
example: effect on the p_T-broadening results when the HERA-B MC is generated taking into account the measured polarization as a function of p_T *and* the possible difference between C and W polarizations (extreme case)

J/ψ and χ_c polarizations are a non-negligible systematic uncertainty in the $R_{\chi c}$ result



J/ψ polarization: summary

- rough interpretation of HERA-B results using toy MC (assuming only direct J/ψ production): a flat polarization generated in the "*parton-parton frame*" (polarization axis parallel to the relative velocity of the interacting partons) gives a decrease of $|\lambda_\theta|$ with increasing p_T in the observable frames, with the 'right' hierarchy (polarization can even change sign from one frame to the other!)



- in the HERA-B case the helicity frame, where the J/ψ momentum is assumed as the reference direction, turns out to be the worst one to observe polarization
- physical interpretation: the polarization is a consequence of the *production process* rather than an intrinsic property of the J/ψ mesons
- the HERA-B data indicate a *longitudinal* J/ψ polarization
- general, concerning polarization measurements:
  - they MUST be made in more than one frame. Unless it is zero, for purely geometrical reasons (smearing due to varying J/ψ kinematics) the polarization automatically *depends* on the frame of observation.
  - the observed hierarchy of frames contains a crucial physical information: how does polarization arise?

χ_c production

selection:

$$\chi_c \longrightarrow J/\psi \ \gamma \qquad J/\psi \rightarrow \begin{cases} e^+e^- \\ \mu^+\mu^- \end{cases}$$

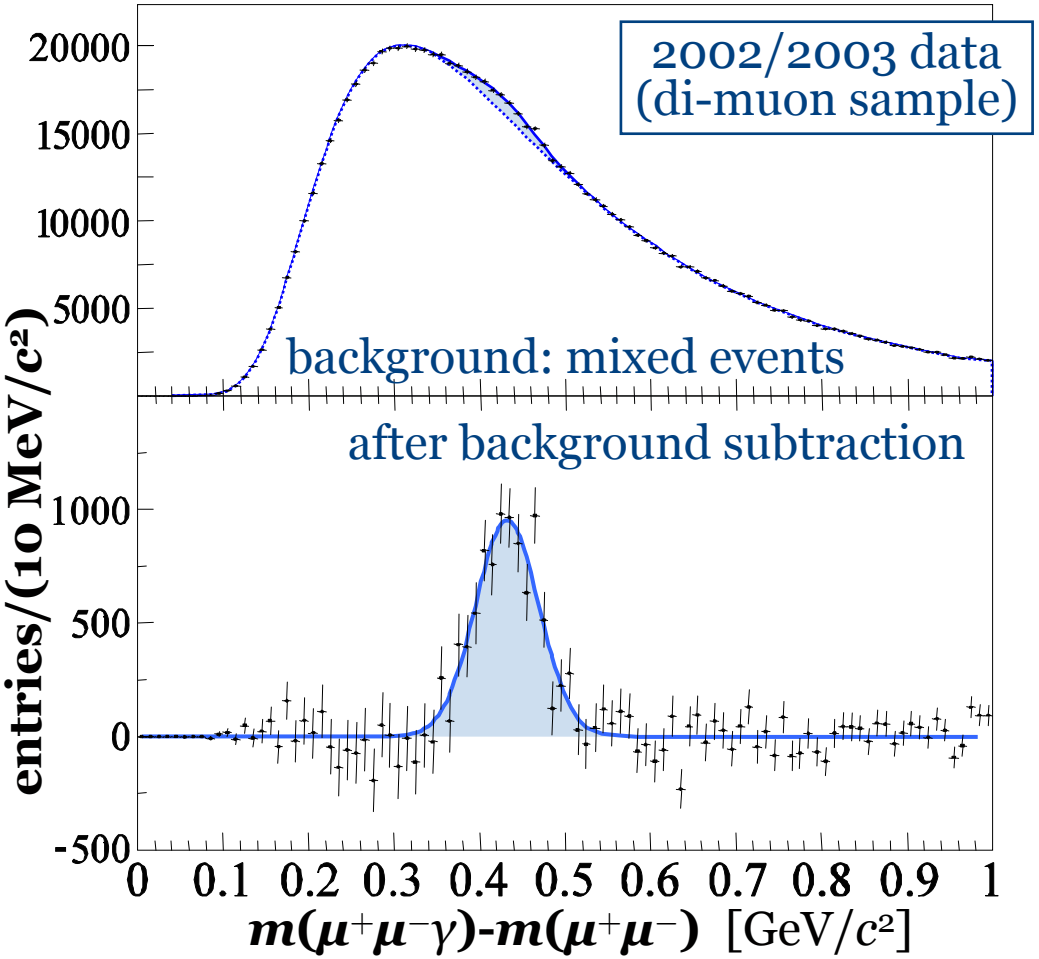
measurement:

- **fraction of J/ψ's from χ_c:**

$$R_{\chi c} = \frac{\sum \sigma(\chi_{c(i)} \rightarrow J/\psi\gamma)}{\sigma_{\mathrm{INCL}}(J/\psi)}$$

- **$\sigma(\chi_{c1})/\sigma(\chi_{c2})$**
- **nuclear dependence**

from the 2000 data, with
370 ± 74 χ_c's ($\mu^+\mu^-$ + e^+e^-):
$R_{\chi c}$ = 0.32 ± 0.06 ± 0.04
[Phys. Lett. B 561, 61 (2003)]



new data: 40× bigger χ_c statistics

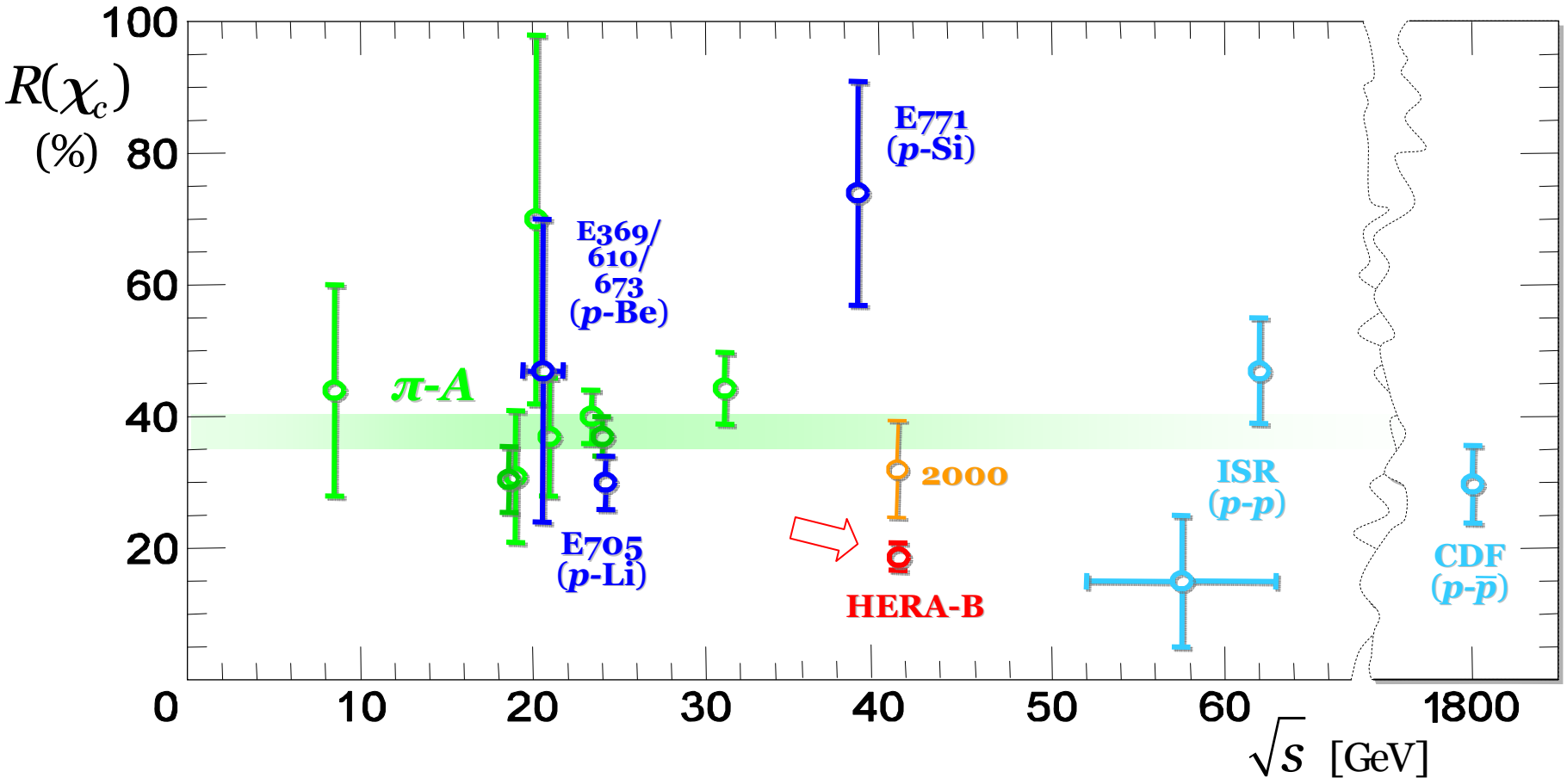
$R(\chi_c)$ – NEW (ALMOST FINAL)

2002/2003 data, full statistics (15000 χ_c's):

$$R(\chi_c) = \begin{cases} (18.0 \pm 2.5_{stat})\% & e^+e^- \\ (19.0 \pm 1.5_{stat})\% & \mu^+\mu^- \end{cases} \Rightarrow$$

$(18.8 \pm 1.3_{stat}\ ^{+2.0}_{-1.8\ syst})\%$ of the produced J/ψ's come from χ_c decays

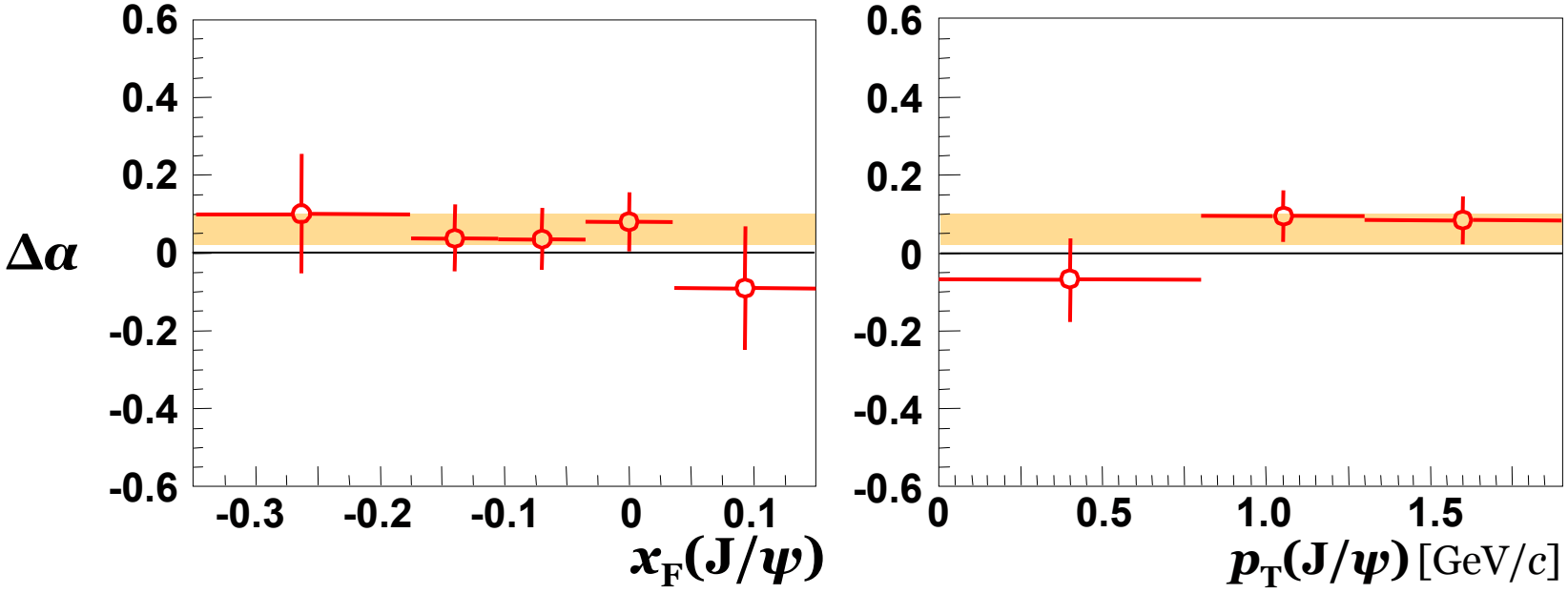
hypotheses on χ_c polarization move the central value within the range 18.3–23.2%



χ_c production: nuclear suppression

Difference in suppression between χ_c and J/ψ:

$$\langle \Delta\alpha \rangle = \langle \alpha(\chi_c) - \alpha(J/\psi) \rangle = 0.05 \pm 0.04$$



how many direct J/ψ's?

[Eur. Phys. J. C49, 545 (2007)]

[Phys. Rev. D 73, 052005 (2006)]

close to final (2002/2003)

$(18.8\,^{+2.4}_{-2.2})\%$

$(7.0\pm0.4)\%$

$(0.065\pm0.011)\%$

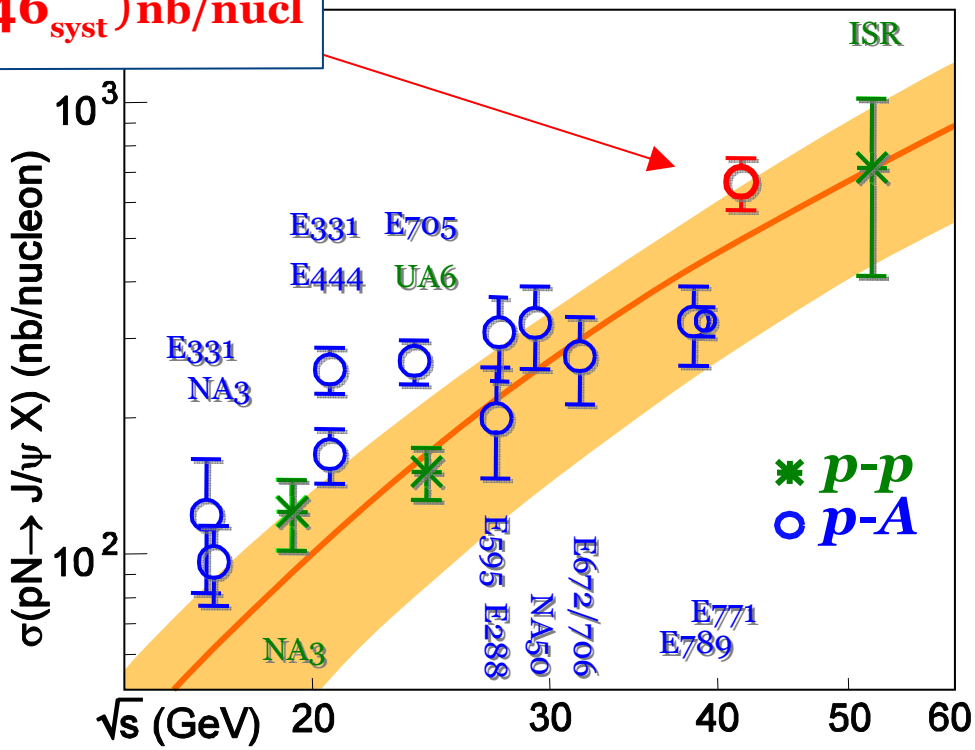
$$\sigma^{J/\psi}_{DIR} = \sigma^{J/\psi}_{INCL}\left[1 - R\left(\chi_c \to J/\psi\right) - R\left(\psi' \to J/\psi\right) - R\left(b \to J/\psi\right) - \dots\right]$$

$\sigma^{J/\psi}_{pN}[41.6\ \text{GeV}] = (663 \pm 74_{stat} \pm 46_{syst})\ \text{nb/nucl}$

[Phys. Lett. B638, 407 (2006)]

$(74.2\,^{+2.2}_{-2.4})\%$ of the J/ψ's are produced directly

curve: NLO NRQCD fit of all data
[Phys. Lett. B 638, 202 (2006)]



summary

- last charmonium results (J/ψ production kinematics and nuclear dependence, polarization, χ_c) will be finalized and submitted for publication soon
- **χ_c production**:
  - updated result confirms a smaller-than-"usual" $R_{\chi c}$ value: more than 70% of the J/ψ's are produced directly
  - probably, χ_c does not suffer a stronger nuclear suppression than J/ψ
- **nuclear dependence of J/ψ production**:
  - measured p_T broadening is in the trend of lower-energy results
  - dependence on x_F cannot be explained easily. Reconsider the role of energy loss?
- **J/ψ polarization**:
  - it can be really measured only by looking at it from *more than one* frame of observation
  - it turns out to arise along the direction of the colliding partons rather than along the flight direction of the J/ψ itself
  - it turns out to be longitudinal